High Speed Machining of IN100

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Final Report

Florida Turbine Technology (FTT)
Jupiter, FL

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14. ABSTRACT
Florida Turbine Technology (FTT) has requested the National Center for Defense Manufacturing and Machining (NCDMM) to evaluate two (2) difficult machining procedures of the HPT shaft. The shaft is manufactured from forged IN100 material which is a very hard, nickel based alloy that is extremely difficult to machine.

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Florida Turbine Technology (FTT)
High Speed Machining of IN100

Prepared by: Doug Perillo

Executive Summary

Florida Turbine Technology (FTT) has requested the National Center for Defense Manufacturing and Machining (NCDMM) to evaluate two (2) difficult machining procedures of the HPT shaft. The shaft is manufactured from forged IN100 material which is a very hard, nickel based alloy that is extremely difficult to machine.

Objectives

FTT does not have a current process in place to manufacture the rotor shaft. The NCDMM will evaluate methods of manufacturing a .250” diameter hole, 4.0 inches deep in the forged IN100 material. The hole will need to maintain a geometric tolerance of .002” true position. The NCDMM will also evaluate methods for High Speed Machining (HSM) of the rotor blade, fin area. This evaluation will consist of machining two (2) complete blades in the forged IN100 material.

Project Details for .250” Diameter Hole

Based on past experience, The NCDMM engineers knew there were only a few methods available for producing a small, tightly positioned, deep hole in the IN100 material. One of these methods is Electrical Discharge Machining (EDM) hole drilling, a process known in the industry as “hole popping”. The process uses a precision tubular electrode to burn the hole into the part. While feeding into the part the tubular electrode is rotating and a deionized water solution is sent thru the tubular electrode as a flushing agent. This method was ruled out based on the effected heat zone left in the hole after processing. There were concerns that this heat zone could result in surface cracks. The hole is a high stress area and this surface damage may cause turbine shaft failure. The NCDMM engineers determined that the chosen method to evaluate would be gun drilling.

A typical gun drill consists of three parts: a carbide tip, a heat-treated alloy shank, and a steel driver. All are typically silver brazed together, and are designed to allow coolant to pass through its entire length. The drill is positioned and held in the spindle nose, then guided into the work piece through a pre-started hole or guide bushing that prevents vibration and ensures accuracy. Gun drill cutting edges form thin, curled chips that are carried away from the bore by high-pressure lubricant. The off-center design of the cutting edges creates pressure within the bore that is carried by pads behind the drill tip. The coolant that flushes the chips also lubricates these pads, which burnish the surface and develop the fine finish for which deep hole gun drilling is known. Gun drilling was developed for use in drilling of cannon barrels, which is were the name “gun drills” come from. See figure 1 and figure 2.

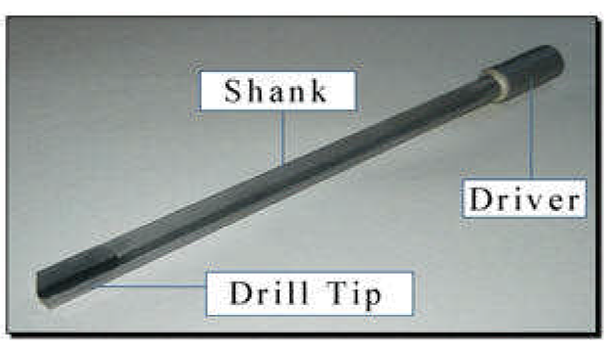

Figure1, Typical Gun Drill Design.

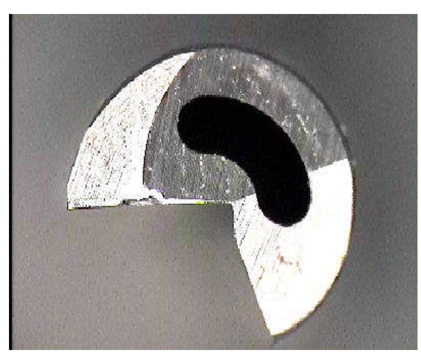

Figure 2, Coolant Hole.

Based on past projects the NCDMM decided to use a gun drill purchased from Star SU. The chosen drill was .250” in diameter by 9” long.

The testing was ran on a Haas VF-6 vertical milling machine with 1000psi coolant at a concentration level of 12%, see figure 3. The process for gun drilling on a milling machine requires a pilot hole to start the drill. This pilot hole was machined in the part using an end mill, see figure 4. The drill is then feed into the guide hole while machine spindle is running in reverse.

Figure 3, Haas VF-6.

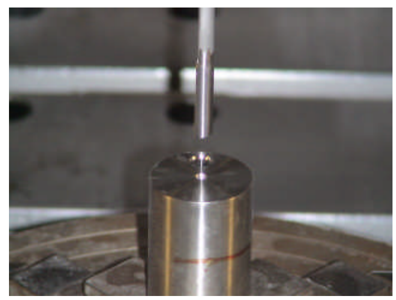

Figure 4, Pilot Hole.

Once the drill is in the guide hole, the machine spindle is switched to forward and the high-pressure coolant is turned “on”. The tool is feed to depth without retracting. Several speed and feed parameters were tested with the best parameters being 40 surface feet per minute (SFM) and .24 inch per minute (IPM). The tool showed good wear characteristics, meaning that the wear was even thru the entire cutting edge, see figure 5 and figure 6.

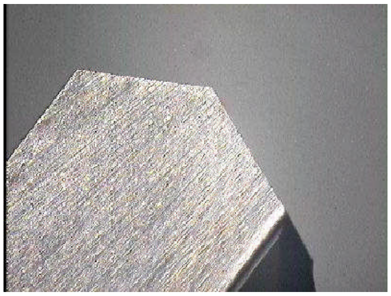

Figure 5, New Drill Cutting Edge.

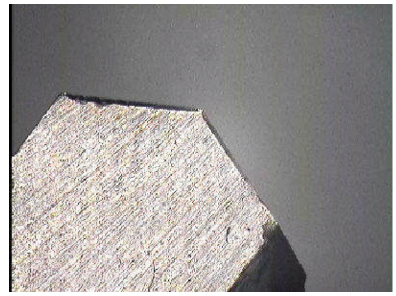

Figure 6, Edge Wear After One Hole.

Once the optimum parameters were found, a final test hole was drilled and checked on the NCDMM lab Coordinate Measuring Machine (CMM), see figure 7. The hole was checked at five (5) depths. The first depth was taken just below the starter hole and subsequent checks were taken at 1” intervals.

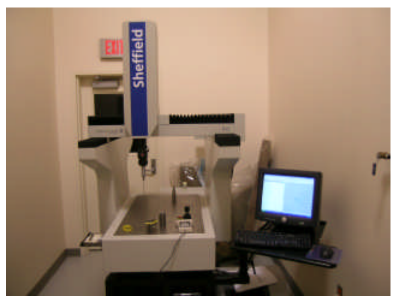

Figure 7, CMM Inspection

The gun drilling process resulted in a 16 minute run time and all geometric hole position requirements were maintained, see attachment A.

<u>Conclusion for .250” Diameter Hole</u>

Based on the findings of this evaluation, the NCDMM feels this is a very viable method of manufacturing the .250” diameter by 4” deep hole. When machining with these parameters the tool preformed well with even wear. Based on the amount of tool wear it is estimated that one tool will produce one hole. The initial tool cost of $80.00 per drill can be offset by the ability to be reground many times. It is estimated that during normal wear these tools can be reground 15 times. The cost for regrinding is roughly $10.00.

The NCDMM recommends that an evaluation be conducted on the advantages of coating the gun drill. Coating will protect the cutting edge and could allow more than one part as well as higher speeds and feeds. There would also be an additional charge for recoating after the regrinding of the tool.

It should also be noted that the location of the hole is extremely close. A true position call out of .002" requires hole placement to be maintained to roughly .0007" max, in both the X-axis and Y-axis direction. Most machine tools will repeat to a positional location within .0003" in the X-axis and Y-axis direction. This means that while the machine moves to the hole location, 50% of your positional tolerance is already used by the machine tool itself. Great care must be used when fixturing and locating the part on the machine tool.

Project Details for Rotor Blade Machining

Currently FTT is not sure on the method of manufacturing the HPT shaft. To date, their two options of consideration are a cast or forged shaft. A cast shaft will be near net shape, meaning the blades will only require a finish cut to bring to final size. A forged shaft will require roughing to bring the blades to a near net shape and also require a finish cut to bring to final size.

Due to limited stock availability, the NCDMM would perform all testing on the end of a forged round bar of IN100 supplied by FTT. All machining would be preformed on a Haas VF-6 vertical milling machine with a rotary trunion table, see figure 8 and figure 9.

Figure 8, Rotary Table.

Figure 9, Haas VF-6 Machine.

Computer aided drafting (CAD) models of the blades were supplied by FTT and all G-code programs were generated with Mastercam version X by the NCDMM technicians, see figure 10 and figure 11. During complex 5-axis tool paths there is always concern for the tool shank hitting the other blades and causing a gouged area. Several 5-axis tool paths were tested for gouge and cycle times.

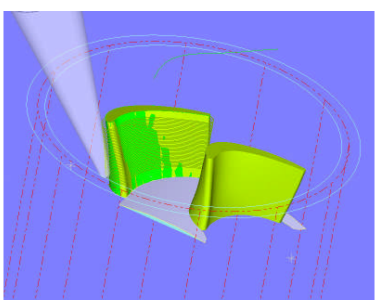

Figure 10, Mastercam Programming.

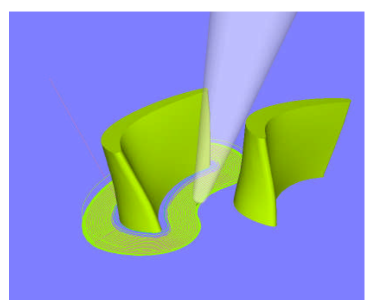

Figure 11, Mastercam Programming.

The tool paths were simulated using verification software. This software is used to verify the G-code that the machine tool runs on, see figure 12 and figure 13.

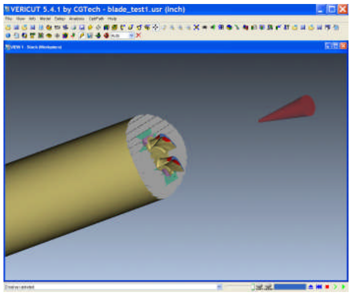

Figure 12, G-code Simulation.

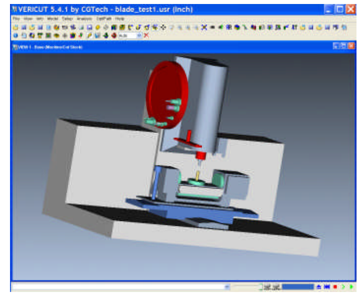

Figure 13, G-code Simulation.

Once the tool paths were determined, a tool size could be selected to assure that the proper clearance could be maintained without gouging the other blades. Roughing was preformed with a Robbjack, MHM-402-03, three (3) millimeter diameter, four (4) flute endmill. Finishing was preformed with a Robbjack, MDM-201-01, one (1) millimeter, two (2) flute ball endmill.

Roughing was preformed at 80 SFM and 2 IPM. Both blades were roughed in one cycle using a surface-roughing path in Mastercam; see figure 14 and figure 15. The roughing cycle resulted in a run time of 18 minutes for two (2) blades. Should FTT determine that the HPT shaft be manufactured form a forged blank, this type of roughing path will be required.

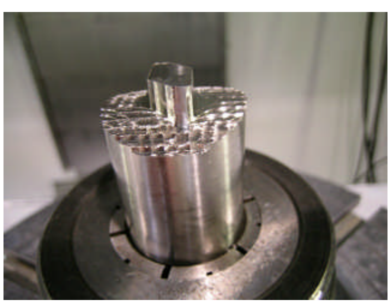

Figure 14, Roughed Blades.

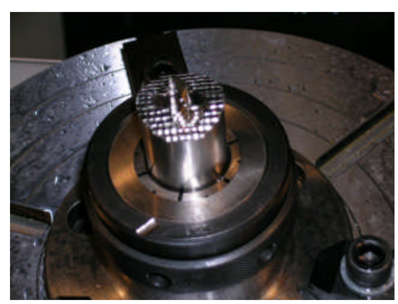

Figure 15, Roughed Blades.

Finishing was preformed at 100 SFM and 4 IPM. Each blade was finished separately resulting in a 30 minute cycle time per blade, see figure 16 and figure 17. The finishing path was generated from Mastercam using a surface 5-axis flow line cycle. Should FTT determine that the HPT shaft will be manufactured from a near net casting, this cycle would be required to maintain the required geometry tolerances as well as the required surface characteristics, see figure 18.

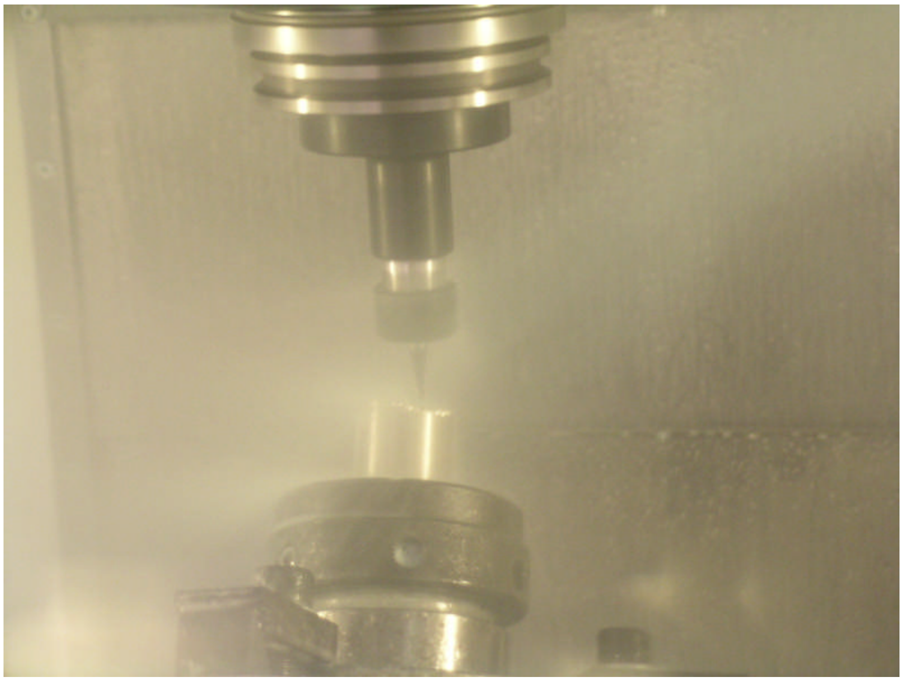

Figure 16, Finishing of the Blades.

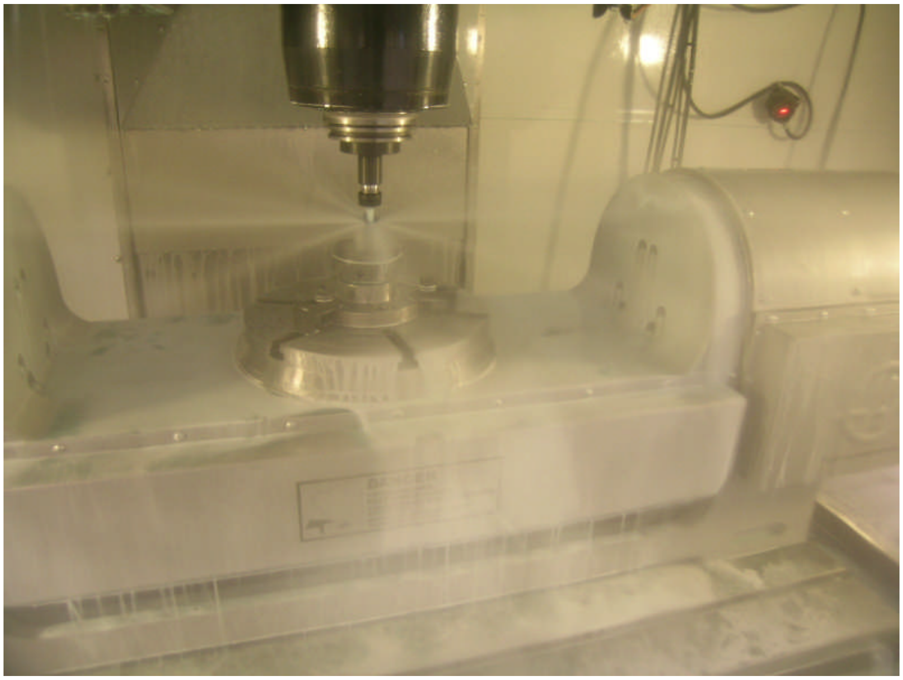

Figure 17, Finishing of the Blades.

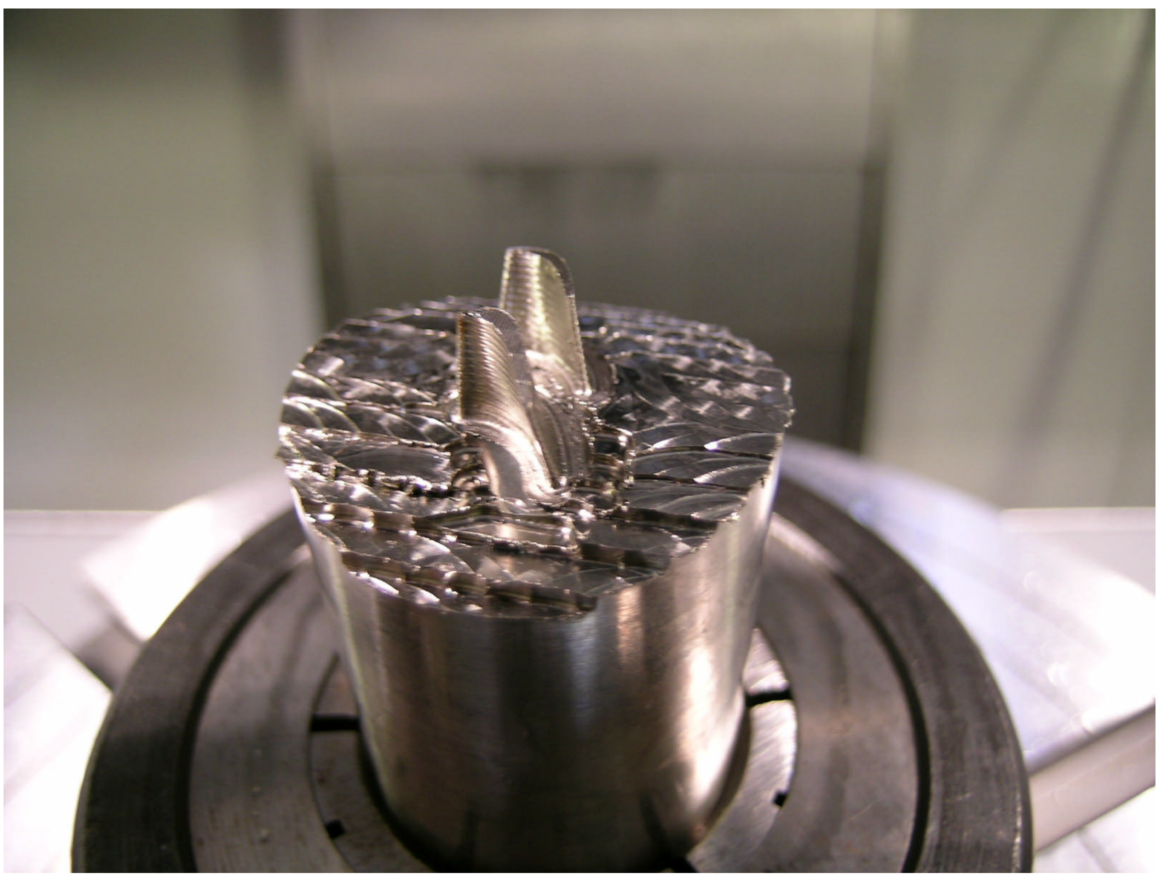

Figure 18, Blades After Finishing Path.

Conclusion for Rotor Blade Machining

The NCDMM believes that this is an acceptable method of manufacturing the HPT rotor blades. There is also much more testing that should be completed. For this type of material there is very little state of the market tooling available for High Speed Machining. The NCDMM recommends that a full material cutting evaluation be preformed on the IN100 final selected material. This should include the evaluation of Cubic Boron Nitride (CBN) tooling. CBN tooling is capable of handling the heat generated from machining at extreme parameters. The NCDMM also recommends that further, full form blade testing be preformed on a machine tool designed for this type of impeller geometry.

Final conclusion

IN100 material is extremely difficult to machine, to date there is limited state of the market tooling available to effectively machine this material, as a result there is very little technical information available on the machining of IN100. Based on these reasons the NCDMM recommends a full machining evaluation of IN100. It should also be noted that this material would machine differently in the forged state as compared to the cast state. It would be beneficial for FTT to finalize the material state before further testing.

Attachment A

NATIONAL CENTER FOR DEFENSE MANUFACTURING & MACHINING

DATE=5/31/2006 TIME=1:17:33 PM
PART NAME : IN100 gundrill test
REV NUMBER : 40 SFM and .0004 IPR
SER NUMBER : center hole part 5 with drill 5
STATS COUNT : 1

⌖ IN	DIM LOC1= TRUE POSITION OF CIRCLE .250 HOLE @ -.375 DEEP		
AX	NOMINAL	MEAS	DEV
X	-0.00017	-0.00017	0.00000
Y	-0.00043	-0.00043	0.00000
DF	0.25088	0.25046	-0.00042
TP	RFS		0.00001

⌖ IN	DIM LOC2= TRUE POSITION OF CIRCLE .250 HOLE @ -.1.0 DEEP		
AX	NOMINAL	MEAS	DEV
X	-0.00017	-0.00040	-0.00023
Y	-0.00043	-0.00049	-0.00006
DF	0.25021	0.25009	-0.00012
TP	RFS		0.00047

⌖ IN	DIM LOC3= TRUE POSITION OF CIRCLE .250 HOLE @ -2.0 DEEP		
AX	NOMINAL	MEAS	DEV
X	-0.00017	-0.00059	-0.00042
Y	-0.00043	-0.00062	-0.00019
DF	0.25055	0.25068	0.00013
TP	RFS		0.00092

⌖ IN	DIM LOC4= TRUE POSITION OF CIRCLE .250 HOLE @ -3.0 DEEP		
AX	NOMINAL	MEAS	DEV
X	-0.00017	-0.00011	0.00006
Y	-0.00043	-0.00061	-0.00018
DF	0.25111	0.25087	-0.00024
TP	RFS		0.00038

⌖ IN	DIM LOC5= TRUE POSITION OF CIRCLE .250 HOLE @ -3.75 DEEP		
AX	NOMINAL	MEAS	DEV
X	-0.00017	-0.00001	0.00016
Y	-0.00043	-0.00073	-0.00030
DF	0.25010	0.25059	0.00049
TP	RFS		0.00068

END OF MEASUREMENT FOR
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